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Computer Method—
Obtaining Radiant Interchange Factors for a Quadruped

D. G. Stevens,[1] J. R. Bohart,[2] and LeRoy Hahn[3]

Introduction

The exchange of an animal's heat to and from its surroundings is necessary for its life. Radiation is one of the modes of heat exchange which transfers heat from an animal's surface to its surroundings. Estimates of the net radiant energy exchange for a body require knowledge of the radiant interchange factor (shape factor). A generalized method for determining various radiant interchange factors for housed quadrupeds (four-legged) using a computer program for evaluation is described in this report. The method is applicable to any animal housing situation in which the surfaces surrounding the animal can be assumed parallel or perpendicular to the centerline of the animal.

Quadruped and Enclosure

A quadruped model is approximated by using seven right circular cylinders (fig. 1). These cylinders represent the four legs, the torso, the neck and the head. The quadruped model assumes the neck parallel to the torso and the head at right angles to the neck.

The quadruped is enclosed within six rectangular surfaces, either parallel or perpendicular to the centerline of the cylinders. A generalized computer program was developed using as input variables the size of the walls and the quadruped's component cylinder and position of the animal within the enclosure. This allows use of the program with many enclosure configurations and various sizes of quadruped.

Determining Radiant Interchange Factors

The radiant energy exchange solution requires finding the interchange factors between each cylinder of the model and a particular enclosing surface. The two basic interchange factors, a finite cylinder to a triangle and a circle to a triangle, were obtained from Tripp, Hwang and Crank.[3] The position of the triangle in relation to the cylinder and circle, the equations and the subroutines to solve these equations are found in the appendix. These integral equations were solved numerically and generalized in a computer program. The remaining shape factors around the sides and ends of the component cylinders were obtained by flux algebra, using methods described by Wiebelt,[4] in the main computer program or its subroutines.[5]

The list of assumptions made in writing the program follows:

1. The legs cannot radiate to the ceiling.
2. The head and neck do not radiate to the rear walls.
3. Only the lower section of the head (below the lower side of the neck cylinder) radiates to the sidewalls.

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[2] Mechanical Engineer, Babcock & Wilcox Co., Power Generation Div., Lynchburg, Va. 24505

[3] Tripp, Wilson, Ching-Lai Hwang, and R. E. Crank. Radiation Shape Factors for Plane Surfaces and Spheres, Circles or Cylinders. Kans. State Univ. Bul. Spec. Rpt. No. 16, vol. 46, No. 4. April 1962.

[4] Wiebelt, J. A. Engineering Radiation Heat Transfer. Holt, Rinehart and Winston, New York. 1966.

[5] A description and program listing of the main program and subroutines (FORTRAN) as developed for use on the IBM 370/165 computer may be obtained by writing the Missouri Climatic Laboratory, Agr. Engin. Dept., Univ. of Mo., Columbia, Mo. 65201

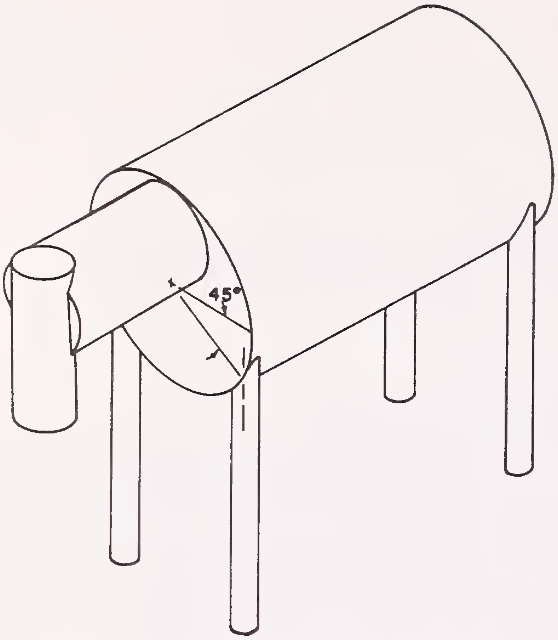

Figure 1.—Placement of cylinders to form model quadruped.

4. The neck cylinder radiates to the section of the radiation panels that extends in front of the body cylinder.

5. The quadruped is standing centered between the sidewalls of the chamber.

6. The required shape factors are calculated for an application only in which all surfaces have black body characteristics.

Example Computations

As an example application to a specific case, the program was used for a quadruped representing a Holstein cow with dimensions approximating those given by Brody.[6] The radius and length (centimeters) of the cylinders used are:

	Radius	*Length*
Legs	3.15	89.0
Body	32.00	127.5
Neck	15.25	57.4
Head	10.16	54.6

The enclosure in this case is an individual environmental chamber in the Missouri Climatic Laboratory. The inside dimensions of the chamber are 285 cm long × 122 cm wide × 193 cm high. The sidewalls have three radiation panels and the ceiling has two radiation panels placed as shown in figures 2 and 3.

By definition, the sum of the shape factors from one surface to all surrounding surfaces must equal 1.0. The shape factors for the body cylinder and rear body circle were used to check the validity of the program. The error, represented by the deviation from unity, for the sum of the body cylinder shape factors was 0.132 percent and for the rear body circle it was 0.44 percent.

Shown below is an example for finding the shape factor from the left rear leg to the rear wall. Five steps are used:

Step 1. The shape factor from the legs to that portion of the wall that is below the top of the leg cylinder and to the right of the leg centerline. This uses the subroutine FAC3. (Shown in Case II in the appendix.)

Step 2: This step is the same as Step 1 but

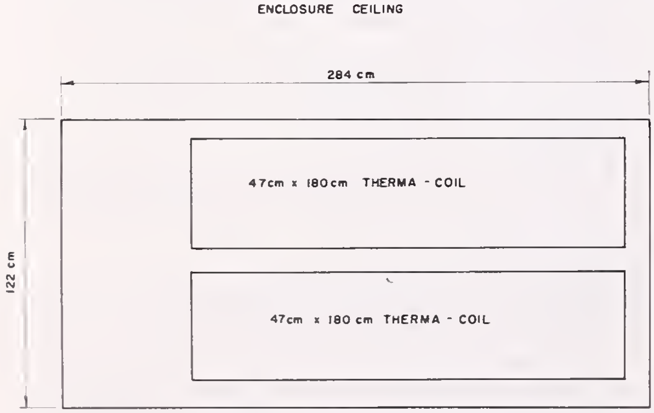

Figure 2.—Ceiling of individual cow chambers.

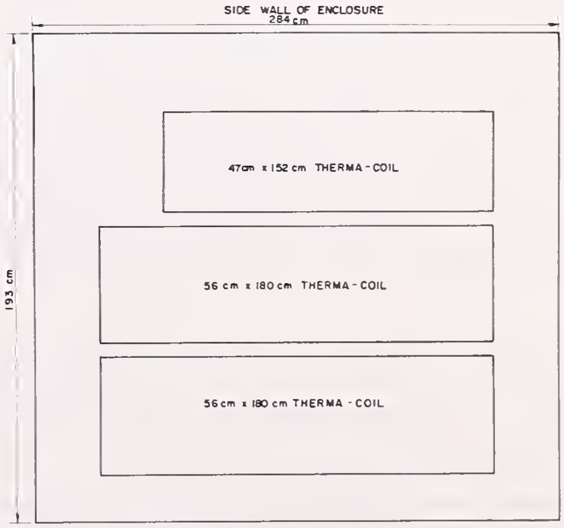
SIDE WALL OF ENCLOSURE
284 cm
193 cm
47cm x 152 cm THERMA - COIL
56 cm x 180 cm THERMA - COIL
56cm x 180 cm THERMA - COIL

Figure 3.—Wall of individual cow chambers.

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[6] Brody, Samuel. Bioenergetics and Growth. Reinhold Publishing Co., New York, p. 650. 1945.

finds the shape factor from the leg to portion of the wall to the left of the leg centerline.

Step 3: The shape factor from the leg to that portion of the wall that is above the top of the leg cylinder and to the right of the leg centerline. This uses the subroutine FAC8 (shown in Case I in the appendix).

Step 4: This step is the same as Step 3 but to the portion of the wall to the left of the leg centerline.

Step 5: The four shape factors found in the preceding steps are summed to find the shape factor from the left leg to the rear wall.

The remaining shape factors are found by applying the two subroutines in various combinations. The complete set of shape factors found by the main program is shown in table 1.

Refinements and Application

The initial program computes shape factors that must be considered a first approximation because of the number of assumptions that were made.

Table 1.—Radiation shape factors for all components

Emitting surface	Body receiving surface	Shape factor
Right rear leg	Right lower radiation panel	0.136387
	Right middle radiation panel	.059776
	Right upper radiation panel	.007587
	Left lower radiation panel	.041207
	Right wall exclusive of radiation panels	.091861
	Rear wall	.150899
	Floor	.277738
Right front leg	Right lower radiation panel	.158680
	Right middle radiation panel	.068826
	Right upper radiation panel	.008038
	Left lower radiation panel	.049300
	Right wall exclusive of radiation panels	.062422
	Front wall	.143710
	Floor	.278445
Left rear leg	Right lower radiation panel	.041207
	Left lower radiation panel	.136387
	Left middle radiation panel	.059776
	Left upper radiation panel	.007587
	Left wall exclusive of radiation panels	.091861
	Rear wall	.150899
	Floor	.277738
Left front leg	Right lower radiation panel	.049300
	Left lower radiation panel	.158680
	Left middle radiation panel	.068826
	Left upper radiation panel	.008038
	Left wall exclusive of radiation panels	.062422
	Front wall	.143710
	Floor	.278445
Body (torso)	Right lower radiation panel	.052813
	Right middle radiation panel	.091062
	Right upper radiation panel	.075321
	Right ceiling radiation panel	.078737
	Left lower radiation panel	.052813
	Left middle radiation panel	.091062
	Left upper radiation panel	.075321
	Left ceiling radiation panel	.078737
	Right wall exclusive of radiation panels	.086526
	Left wall exclusive of radiation panels	.086526
	Ceiling exclusive of radiation panels	.041240
	Front wall	.016158
	Rear wall	.017494
	Floor	.154872
	Total (body)	0.998678

Table 1.—Radiation shape factors for all components—Continued

Emitting surface	Rear body circle receiving surface	Shape factor
Neck	Left or right lower radiation panel	0.003462
	Left or right middle radiation panel	.032240
	Left or right upper radiation panel	.028295
	Left or right ceiling radiation panel	.063411
	Left or right wall exclusive of radiation panels	.166015
	Ceiling exclusive of radiation panels	.122637
Head	Left or right lower radiation panel	.009473
	Left or right middle radiation panel	.054247
	Left or right upper radiation panel	.010922
	Left or right wall exclusive of radiation panels	.062841
	Front wall	.412551
Front body circle	Left or right lower radiation panel	.007960
	Left or right middle radiation panel	.030836
	Left or right upper radiation panel	.016153
	Left or right ceiling radiation panel	.009692
Rear body circle	Right lower radiation panel	.001747
	Right middle radiation panel	.008116
	Right upper radiation panel	.003331
	Right ceiling radiation panel	.002854
	Left lower radiation panel	.001747
	Left middle radiation panel	.008116
	Left upper radiation panel	.003331
	Left ceiling radiation panel	.002854
	Right wall exclusive of radiation panels	.143718
	Left wall exclusive of radiation panels	.143718
	Ceiling exclusive of radiation panels	.085124
	Rear wall	.550211
	Floor	.050806
	Total (rear body circle)	1.005672

Refinements that could be incorporated are approximating the quadruped using right circular ellipses, truncated cylindrical cones or truncated elliptical cones.

Physical models of total heat balance for quadrupeds as developed for the pig by Beckett and Vidrine[7] require evaluation of radiation heat transfer. The method of obtaining radiant interchange factors outlined in this report should expedite estimating the radiation component of the total heat balance.

Appendix

The shape factor for radiation from a finite cylinder to a surface that is parallel to the centerline of the cylinder cannot be determined directly. The radiation being received by surface **B**, in figure 4, and the two right triangles connecting the surface and the cylinder is equal to the radiation leaving the shaded portion, **A**, of the cylinder. Therefore, to find the radiation leaving the cylinder and striking the surface **B**, that is, the shape factor, the radiation passing through the two triangles is subtracted from that leaving **A**.

Finite Cylinder To a Right Triangle

Figure 5 shows a view of the cylinder and the placement of the right triangle for development of the equation. The detailed explanation (next page) of the solution of this shape factor is given by Tripp and others.[8]

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[7] Beckett, F. E. and Clyde Vidrine. A Mathematical Model of Heat Transfer in a Pig. Trans. of ASAE 13(4): 450-454. 1970.

[8] See footnote 3, page 1.

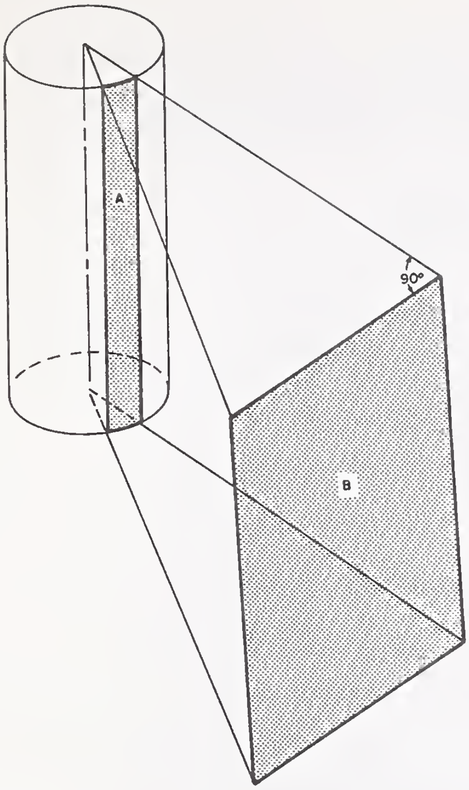

Figure 4.—Finite cylinder to a parallel surface.

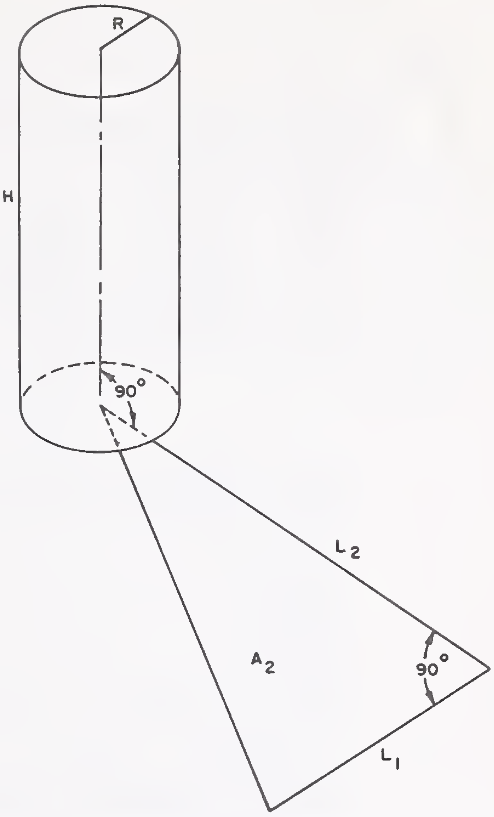

Figure 5.—Placement of right triangle to develop equation.

$$F_{A_1,A_2} = F_{12} = \frac{A_2}{A_1} F_{A_2,A_1} = \frac{1}{2\pi^2 W}\Bigg\{ \int_1^{\sqrt{B^2+C^2}} \tan^{-1}\frac{B}{C} \Bigg[\tan^{-1}\sqrt{\frac{a+1}{a-1}}$$

$$- \frac{W^2+(a+1)(a-1)}{\sqrt{\{W^2+(a+1)^2\}\ \{W^2+(a-1)^2\}}} \tan^{-1}\sqrt{\frac{(a-1)\ \ \{W^2+(a+1)^2\}}{(a+1)\ \ \{W^2+(a-1)^2\}}}\ \Bigg] a da$$

$$- \int_C^{\sqrt{B^2+C^2}} \Bigg[\tan^{-1}\sqrt{\frac{a+1}{a-1}}$$

$$- \frac{W^2+(a+1)(a-1)}{\sqrt{\{W^2+(a+1)^2\}\ \{W^2+(a-1)^2\}}} \tan^{-1}\sqrt{\frac{(a-1)\ \ \{W^2+(a+1)^2\}}{(a+1)\ \ \{W^2+(a-1)^2\}}}\ \Bigg] \sec^{-1}\frac{a}{c}\ \ a da \Bigg\}$$

where

$B = \frac{L_1}{R}$, $C = \frac{L_2}{R}$, $W = \frac{H}{R}$, $a = \frac{}{R}$, is an increment of $\sqrt{B^2 + C^2}$

This equation is evaluated in the subroutine FACTOR (next page) which uses numerical quadrature to evaluate the integrals.

```
    SUBROUTINE FACTOR (AL1,AL2,H,R,AAREA)
C                                                                           C
C***************************************************************************C
C                                                                           C
C   THIS SUBROUTINE FINDS THE SHAPE FACTOR FROM A CYLINDER TO A RIGHT       C
C   TRIANGLE WHICH IS PERPENDICULAR TO THE CENTERLINE AND EVEN WITH ONE     C
C   END OF THE CYLINDER.                                                    C
C                                                                           C
C       AL1   = LENGTH OF OPPOSITE SIDE OF TRIANGLE                         C
C       AL2   = LENGTH OF ADJACENT SIDE OF TRIANGLE                         C
C       H     = HEIGHT OF CYLINDER                                          C
C       R     = RADIUS OF CYLINDER                                          C
C       AAREA = SHAPE FACTOR                                                C
C                                                                           C
C***************************************************************************C
C                                                                           C


      DOUBLE PRECISION A,ZA,B,C,W,W2,AP1,AM1,TBC,AR(309),B2,C2
      DOUBLE PRECISION AP12,AM12,ZB1,ZB2,ZB,ZC,ZD,ANC
      DOUBLE PRECISION AREA1,AREA2
      B=AL1/R
      C=AL2/R
      W=H/R
      ITTER=300
      B2=B**2
      C2=C**2
      ANC=(DSQRT(B2+C2)-1.0)/FLOAT(ITTER)
      IT=ITTER+1
      A=1.000001
      W2=W**2
      TBC=DATAN(B/C)
      DO 1 I=1,IT
      AP1=A+1.0
      AM1=A-1.0
      ZA=DATAN(DSQRT(AP1/AM1))
      AP12=AP1**2
      AM12=AM1**2
      ZB1=W2+AP12
      ZB2=W2+AM12
      ZB=W2+AP1*AM1
      ZC=AB/DSQRT(ZB1*ZB2)
      ZD=DATAN(DSQRT((AM1*ZB1)/(AP1*ZB2)))
      AR(I)=TBC*(ZA-ZC*ZD)*A
    1 A=A+ANC
      CALL QUADR(AR,IT,ANC,AREA1,ITER)
      ANC=(DSQRT(B2+C2)-C)/FLOAT(ITTER)
      A=C
      DO 3 I=1,IT
      AP1=A+1.0
      AM1=A-1.0
      AP12=AP1**2
      AM12=AM1**2
      ZB1=W2+AP12
      ZB2=W2+AM12
      ZB=W2+AP1*AM1
      ZC=ZB/DSQRT(ZB1*ZB2)
      ZD=DATAN(DSQRT((AM1*ZB1)/(AP1*ZB2)))
      AR(I)=DARCOS(C/A)*A*(ZA-ZC*ZD)
    3 A=A+ANC
      CALL QUADR(AR,IT,ANC,AREA2,ITER)
      AAREA=(0.0506606/W)*(AREA1-AREA2)
      RETURN
      END
```

```
C                                                                      C
C**********************************************************************C
C                                                                      C
C  S U B R O U T I N E   Q U A D R A T U R E                           C
C                                                                      C
C  PURPOSE:                                                            C
C     INTEGRATES A GIVEN TABULATED FUNCTION AT A SET OF EQUALLY SPACED C
C     POINTS.                                                          C
C                                                                      C
C  USAGE:                                                              C
C     CALL QUADR(Z,N,H,S IER)                                          C
C                                                                      C
C  DESCRIPTION OF PARAMETERS:                                          C
C     Z   = A VECTOR OF LENGTH N CONTAINING THE VALUES OF THE FUNCTION C
C           TO BE INTEGRATED                                           C
C     N   = THE NUMBER OF FUNCTION VALUES TO BE INTEGRATED             C
C     H   = THE SPACING OF THE FUNCTION VALUES                         C
C     S   = THE RESULTANT VALUE OF THE COMPUTED INTEGRAL               C
C     IER = RESULTANT ERROR CODE WHERE IER=0 INDICATES NO ERROR, IER=1 C
C           INDICATES N LESS THAN 2, IER=2 INDICATES H=0.              C
C                                                                      C
C  REMARKS:                                                            C
C     SEE ERROR CODES ABOVE.                                           C
C                                                                      C
C  METHOD:                                                             C
C     NUMERICAL QUADRATURE IS PERFORMED USING A 5 POINT FORMULA UNTIL  C
C     FEWER THAN 5 POINTS REMAIN.  A 4, 5, OR 2 POINT FORMULA IS THEN  C
C     USED TO COMPLETE THE INTEGRATION.                                C
C                                                                      C
C**********************************************************************C
C                                                                      C
      SUBROUTINE QUADR(Z,N,H,S,IER)
C                                                                      C
C**********************************************************************C
C                                                                      C
C  IF A DOUBLE PRECISION VERSION OF THIS ROUTINE IS DESIRED, THE C IN  C
C  COLUMN 1 SHOULD BE REMOVED FROM THE DOUBLE PRECISION STATEMENT WHICHC
C  FOLLOWS.                                                            C
C                                                                      C
C**********************************************************************C
C                                                                      C
      DOUBLE PRECISION Z,H,S
      S=.0
      IF(N-1)32,32,33
   32 IER=1
      RETURN
   33 IF(H)34,35,34
   35 IER=2
      RETURN
   34 IF(N-5)40,38,38
C                                                                      C
C     CALCULATE USING 5 POINT FORMULA                                  C
C                                                                      C
  38 DO 39 I=5,N,4
  39 S=S+7.*Z(I-4)+32.*Z(I-3)+12.*Z(I-2)+32.*Z(I-1)+7.*Z(I)
     S=S*2./45.
  40 J=N-(N/4)*4+1
     GO TO (45,50,47,48),J
C                                                                      C
C    CALCULATE USING 4 POINT FORMULA                                   C
C                                                                      C
  45 S=S+.375*(Z(N-3)+3.*Z(N-2)+3.*Z(N-1)+Z(N))
     GO TO 50
C                                                                      C
C    CALCULATE USING 2 POINT FORMULA                                   C
C                                                                      C
  47 S=S+(Z(N-1)+Z(N))/2.
     GO TO 50
C                                                                      C
C    CALCULATE USING 3 POINT FORMULA                                   C
C                                                                      C
  48 S=S+(Z(N-2)+4.*Z(N-1)+Z(N))/3.
  50 S=S*H
     IER=0
     RETURN
     END
```

Finite Circle To a Right Triangle

The shape factor found from this subroutine is used to find the shape factors from the end circles of the body to the walls, shown in figure 6. A detailed explanation of the procedure is given by Tripp and others[9]

$$F_{12} = \frac{1}{4\pi X^2} \left\{ \left[\frac{1}{YZ} + (1 + X^2) \tan^{-1} \frac{Z}{Y} \right] - \int_0^{\tan^{-1} \frac{Z}{Y}} \sqrt{\frac{1}{Z^2} \quad (Z^2 + X^2Z^2 + \sec^2\phi)^2 - 4X^2Z^2 \sec^2\phi d\phi} \right\}$$

where

$$X = \frac{R}{D}, \; Y = \frac{D}{L_1}, \; Z = \frac{D}{L_2}$$

The preceding equation is evaluated in the subroutine CIRFAC.

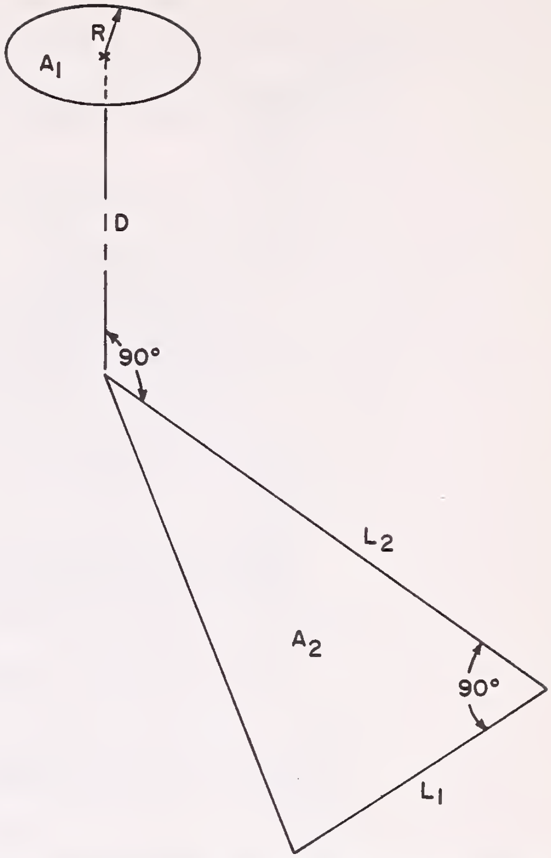

Figure 6—Placement of the right triangle in relation to the circle and the numbers used in the equation to find the shape factor.

```
      SUBROUTINE CIRFAC(AL1,AL2,D,R,AAREA)
C                                                                        C
C************************************************************************C
C                                                                        C
C  THIS SUBROUTINE FINDS THE RADIATION SHAPE FACTOR FROM A CIRCLE TO A   C
C  RIGHT TRIANGLE THAT IS PARALLEL TO THE CIRCLE.                        C
C                                                                        C
C     AL2   = LENGTH OF ADJACENT SIDE OF TRIANGLE                        C
C     AL1   = LENGTH OF OPPOSITE SIDE OF TRIANGLE                        C
C     D     = NORMAL DISTANCE BETWEEN CIRCLE AND TRIANGLE                C
C     R     = RADIUS OF CIRCLE                                           C
C     AAREA = SHAPE FACTOR                                               C
C                                                                        C
C************************************************************************C
C                                                                        C
      DOUBLE PRECISION X,Y,Z,X2,TZY,Z2,ANC,A,CONST,SEC2,AR(309),AREA1
      X = R/D
      Y = D/AL1
      Z = D/AL2
      X2 = X*X
      TZY = DATAN(Z/Y)
      Z2 = Z*Z
      ITTER = 300
      ANC = TZY/FLOAT(ITTER)
      IT = ITTER+1
      A = 0.0
      CONST = (1.0/(Y*Z)+(1.0+X2)*TZY)
      DO 1 I=1,IT
      SEC2 = (1.0/DCOS(A))**2.0
      AR(I) = (DSQRT((Z2+X2*Z2+SEC2)**2.0-4.0*X2*Z2*SEC2))/Z2
    1 A = A+ANC
      CALL QUADR(AR,IT,ANC,AREA1,ITER)
      AAREA = (CONST-AREA1)/(4.0*3.1417*X2)
      RETURN
      END
```

---

[9] See footnote 3, page 1.

Circle To a Rectangular Wall

In this subroutine, the wall is perpendicular to the plane of the circle, shown in figure 7. The shape factor $F_{C_1 \rightarrow 1}$ is found from the following equations:

$$F_{C_1 \rightarrow 1} = F_{C_1 \rightarrow (1 + 2)} - F_{C_1 \rightarrow 2}$$

$$F_{C_1 \rightarrow 2} = \text{CALL CIRFAC (A,B,D,R,F1)}$$

$$F_{C_1 \rightarrow (1 + 2)} = \frac{1}{2} \tan^{-1} \quad (A/B)$$

The CIR1 subroutine implements the preceding equations.

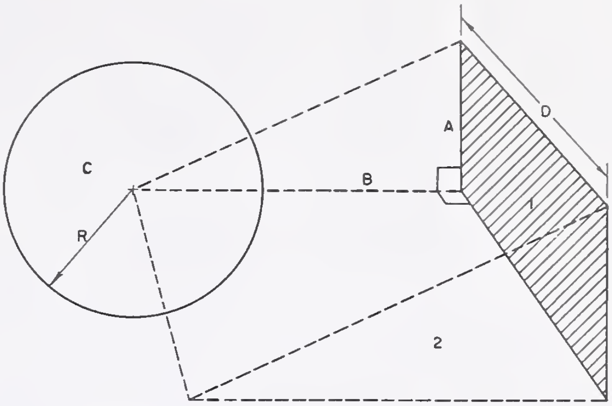

Figure 7.—End circle in relation to a wall.

```
      SUBROUTINE CIR1(A,B,D,R,F)

C                                                                       C
C***********************************************************************C
C                                                                       C
C   THIS SUBROUTINE FINDS THE SHAPE FACTOR FROM A CIRCLE TO A RECTANGLE C
C   EVEN AND NORMAL TO THE PLANE OF THE CIRCLE.                         C
C                                                                       C
C     A = HEIGHT OF RECTANGLE                                           C
C     B = RADIAL DISTANCE FROM CENTER OF CIRCLE TO RECTANGLE            C
C     D = LENGTH OF RECTANGLE                                           C
C     R = RADIUS OF CIRCLE                                              C
C     F = SHAPE FACTOR                                                  C
C                                                                       C
C***********************************************************************C
C                                                                       C

      CALL CIRFAC(A,B,D,R,F1)
      F2 = ATAN(A/B)/(2.0*3.1417)
      F = F2-F1
      RETURN
      END
```

Case I

In this case, the radiation shape factor to be found is from a cylinder to a wall that is parallel to the centerline of the cylinder and the bottom of the wall is the top of the cylinder, from cylinder C1 to Wall 1.

The equation is numbered as in figure 8, and the radiating shape factor $F_{C_1 \rightarrow 1}$ is found from the equations that follow.

$$F_{C_1 \rightarrow 1} = F_{C_1 \rightarrow 4} - F_{C_1 \rightarrow 3}$$

$$F_{C_1 \rightarrow 4} = \text{CALL FACTOR (B,A,H,R,F1T4)}$$

$$F_{C_1 \rightarrow 3} = \frac{A_{C_1} + A_{C_2}}{A_{C_1}} F_{(C_1 + C_2) \rightarrow 3} - \frac{A_{C_2}}{A_{C_1}} F_{C_2 \rightarrow 3}$$

$$F_{(C_1 + C_2) \rightarrow 3} = \text{CALL FACTOR (B,A,H+C,R,F12T3)}$$

$$F_{C_2 \rightarrow 3} = \text{CALL FACTOR (B,A,C,R,F2T3)}$$

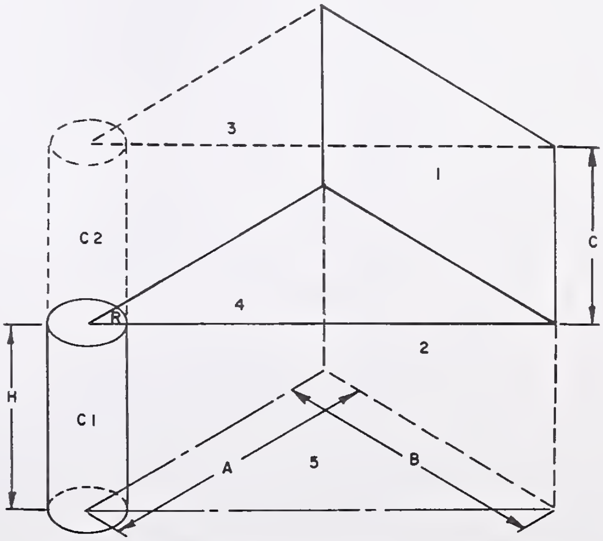

Figure 8.—Placement of cylinder C1 and Wall 1.

The FAC8 subroutine implements the above formula.

```
      SUBROUTINE FAC8(A,B,C,H,R,F)
C                                                                      C
C**********************************************************************C
C   THIS SUBROUTINE FINDS THE RADIATION SHAPE FACTOR FOR A CYLINDER    C
C   TO A WALL WHICH IS PARALLEL TO THE CENTERLINE OF THE CYLINDER AND  C
C   THE BOTTOM OF THE WALL IS AT THE TOP OF THE CYLINDER.              C
C                                                                      C
C   THE PARAMETERS ARE-                                                C
C                                                                      C
C       A = THE PERPENDICULAR DISTANCE FROM THE WALL TO THE CYLINDER   C
C       B = THE LENGTH OF THE WALL                                     C
C       C = THE HEIGHT OF THE WALL                                     C
C       H = THE HEIGHT OF THE CYLINDER                                 C
C       R = THE RADIUS OF THE CYLINDER                                 C
C       F = THE SHAPE FACTOR FROM THE CYLINDER TO THE WALL             C
C**********************************************************************C
C                                                                      C

      ANGLE=ATAN(B/A)
      AC1=R*H*ANGLE
      AC2=R*C*ANGLE
      CALL FACTOR (B,A,C,R,F2T3)
      CALL FACTOR(B,A,H+C,R,F12T3)
      F1T3=((AC1+AC2)/AC1)*F12T3-(AC2/AC1)*F2T3
      CALL FACTOR (B,A,H,R,F1T4)
      F=F1T4-F1T3
      RETURN
      END
```

Case II

In this case, the radiation shape factor to be computed is from a cylinder to a wall in which the wall is the same height as the cylinder, and the bottom of the wall is even with the bottom of the cylinder. The numbers assigned to the surfaces in figure 9 are used in the equations for determining $F_{C_1 \to 2}$

The following are equations to find $F_{C_1 \to 2}$.

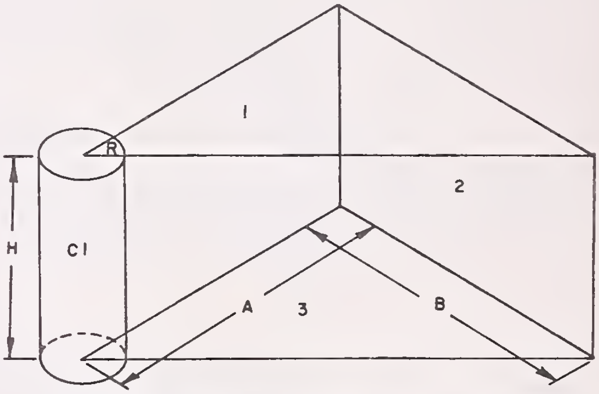

Figure 9.—Placement of cylinder C1 and Wall 2.

CALL FACTOR (B,A,H,R,F1T1)

FAC3 subroutine implements the above equations:

$$F_{C_1 \to 2} = F_{C_1 \to (1+2+3)} - F_{C_1 \to 1} - F_{C_1 \to 3}$$

$$F_{C_1 \to (1+2+3)} = \frac{1}{2\pi} \tan^{-1} (B/A)$$

$$F_{C_1 \to 1} = F_{C_1 \to 3} = \text{CALL FACTOR } (B,A,H,R,F1T1)$$

```
      SUBROUTINE FAC3(A,B,H,R,F)
C                                                                      C
C**********************************************************************C
C    THIS SUBROUTINE FINDS THE RADIATION SHAPE FACTOR FROM A CYLINDER  C
C    TO A WALL WHICH IS PERPENDICULAR TO THE CYLINDER AND THE SAME     C
C    HEIGHT.                                                           C
C                                                                      C
C    THE PARAMETERS ARE-                                               C
C         A = PERPENDICULAR DISTANCE FROM THE CYLINDER TO THE WALL     C
C         B = LENGTH OF THE WALL                                       C
C         H =  HEIGHT OF THE WALL AND CYLINDER                         C
C         R = RADIUS OF THE CYLINDER                                   C
C         F = RADIATION SHAPE FACTOR FROM CYLINDER TO WALL             C
C                                                                      C
C**********************************************************************C
C                                                                      C

      CALL FACTOR(B,A,H,R,F1T1)
      AND - 0.159155 * ATAN (B/A)
      F = ANG-.2*F1T1
      RETURN
      END
```